UTILITY PATENT APPLICATION

MICROMECHANICAL MONOCHROMATOR WITH INTEGRATED SLIT APERTURE FOR MICROSPECTROMETERS IN THE UV, VISIBLE AND INFRARED RANGE

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[01] MICROMECHANICAL MONOCHROMATOR WITH INTEGRATED SLIT APERTURE FOR MICROSPECTOMETERS IN THE UV, VISIBLE AND INFRARED RANGE

[02] Cross Reference to Related Applications

[03] This application claims priority of, and expressly incorporates by reference, U.S. Provisional Application Serial No. 60/412,535 filed September 20, 2002.

[04] Field of the Invention

[05] The invention relates to the domain of optical spectroscopy with the intention to simplify the construction and arrangement of micromechanical monochromators based on MEMS (Micro Electro Mechanical Systems) technology and its applications. This invention allows for an ultracompact, lightweight, high resolution and reproducible construction of a micro mechanical spectrometer working in the UV, Visible, and Infrared Range.

[06] Background

[07] In U.S. patent 4,867,532, Stanley described a wavelength selection device having a diffraction grating mounted on a torsion member. He also claimed a monolithic torsion diffraction grating, which is directly integrated on the surface of the monolithic movable torsion element, with the grating parallel to the mechanical axis. However no claims have been made about the wavelength resolution and efficiency of this device.

[08] Reffner et al. in U.S. Patent 4,922,104 and Eguchi et al. in U.S. Patent 4,922,104 disclose an infrared micromirror spectrometer attached to a microscope apparatus, which is suitable for accurately identifying the material at a microfine portion. Although this device enables high sensitivity spectral measurements the system is highly complex and is not suitable for remote handheld operations. Furthermore, Zavracky proposes in U.S. Patent 5,909,280 a method of monolithically fabricating a microspectrometer with an integrated detector. This microspectrometer can be integrated into a sensor system to measure the optical and physical properties of solids and fluids. The disadvantage of this instrument is that its detection sensitivity is limited.

[09] SUMMARY OF AT LEAST ONE EMBODIMENT OF THE INVENTION

[10] Brief Description of One Embodiment of the Present Invention

[11] The present invention may provide scanning micromechanical monochromators /spectrometers with a dispersive controllable element that is either built with a monolithic torsion mirror with a related fixed diffraction grating or with a monolithic torsion diffraction grating, and a fixed spatial filter at the entrance and exit slit. In addition to this important physical miniaturization, a significant simplification of the spectrometers beam path is gained by using advanced MEMS (Micro Electro Mechanical Systems) technology.

[12] The above description sets forth, rather broadly, a summary of at least one embodiment of the present invention so that the detailed description that follows may be better understood and contributions of the present invention to the art may be better appreciated. Some of the embodiments of the present invention may not include all of the features or characteristics listed

in the above summary. There are, of course, additional features of the invention that will be described below and will form the subject matter of claims. In this respect, before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details of the construction and to the arrangement of the components set forth in the following description or as illustrated in the drawings. The invention is capable of other embodiments and of being practiced and carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting.

[13] BRIEF DESCRIPTION OF THE DRAWINGS

[14] Fig.1 is substantially a conventional micro mechanical monochromator in autocollimation assembly with torsion mirror, fixed diffraction grating, and off-axis parabolic reflector.

[15] Fig.2 is substantially a monochromator like Fig.1 with collimator lens and torsion diffraction grating.

[16] Fig.3 is substantially a cross sectional view of the rotation axis for a monochromator according to the invention, with slit apertures on the axis of the torsion diffraction grating.

[17] Fig.4 is substantially a schematic side view of the design according to Fig.3.

[18] Fig.5 is substantially a topological reproduction of exemplary designs of slit apertures on the monolithic body of the torsion diffraction grating.

[19] Fig.6 is substantially a schematic optical system layout for micromirror spectrometer with an oscillating scanning mirror and diffraction grating combination.

[20] DESCRIPTION OF CERTAIN EMBODIMENTS OF THE PRESENT INVENTION

[21] In the following detailed description of certain embodiments of the present invention, reference is made to the accompanying drawings, which form a part of this application. The drawings show, by way of illustration, specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made with out departing from the scope of the present invention.

[22] Five exemplary approaches to optical arrangements for the measurement of spectra in specific regions are shown in **Figs 1 through 5**. The invention relates to spectrometers in general (covering the UV, Visible and Infrared range), which are designed with the microspectrometer according to the invention as well as radiation detectors for the measurement of the decoupled monochromatic radiation and a related analyzing unit. The drawings are schematic and the diffraction angles are illustrative and not exact.

[23] **Figure 1** is a schematic optical layout according to the principle of the present invention. Radiation in the form of photons, for example an infrared beam, proceeds from a light source and is collimated through the entrance slit **1** and then strikes a curved parabolic mirror which makes the polychromatic light beam parallel. In another embodiment of this invention a micromirror **6** scans the input light over a fixed diffraction grating **5**, which disperses the spectrum. The spectrum is then reflected back to the detector plane (exit slit **2**). One specific feature of the layout is that the MEMS oscillating micromirror is separate from the grating. Moreover, in this design, the slit apertures **1** and **2** are a part of the miniaturization and need not be adjusted

separately. In addition, the spectrum is scanned via tilting motion of the micromechanical torsion element **6**. Design and function of such micromechanical diffraction gratings are known from U.S. Patent 4867532. However, variations in the options of the drive (electrostatic, electromagnetic, resonance driven, capacitive controlled) are further design criteria of the invention. The arrangement of the optical elements of the example in autocollimation is no restriction to the invention.

[24] **Figure 2** reveals another scheme of the construction and the function of the monochromator in autocollimation as shown in **Fig. 1**with achromatic collimator lens **9** and integrated torsion diffraction grating **5a**. The wavelength selection device **5a** is comprised of a diffraction grating mounted to a torsion micromirror. A pair of electrodes **7, 8** is responsive for the electrostatic deflection. The micromechanical diffraction grating in the example consists substantially of an electrode mounting on the backside with electrodes **7, 8.** A controllable power supply generates defined electrode potentials in order to accelerate the torsion element by electrostatic forces. The fixed entrance spatial filter generates the parallel polychromatic radiation. The desired parallel monochromatic partial radiation is selected and decoupled due to the fixed exit spatial filter. The spatial filters contain collimation optics to guide and focus the radiation, like mirrors **4** or lenses **9**, where small apertures are located in their focus. These are usually slit apertures **1, 2** and/or optical waveguides and/or detectors.

[25] **Figure 3** is a preferred embodiment of this invention consisting of the optical beam path of the exemplary monochromator. It basically consists of a movable integrated diffraction grating torsion mirror **5a**, with electrodes **7, 8** and a common spherical collimator mirror **11** with mirror's optical axis **10,** where **12** represents the zero order of diffraction which is absorbed by

surface screen **A**. With the help of the dispersive element **5a,** parallel polychromatic radiation is dispersed spatially into almost parallel monochromatic radiation, while the direction of this monochromatic radiation is controlled via tilting. Due to the small numerical aperture, the spherical aberration of the spherical collimator mirror **11** is relatively small, so that an expensive parabolic reflector is not necessary. The polychromatic radiation to be analyzed by the optical waveguide **13,** located on the backside of the entrance slit aperture passes the aperture and arrives diverged at the collimator mirror. After reflection from the collimator mirror the almost parallel radiation bundle illuminates the diffraction grating **5a**. In this case the incidence angle onto the diffraction grating is determined by the actual angle position of the torsion element **6**. The radiation part of the zero diffraction order **12** leaves the diffraction grating towards the screen **A** and will be absorbed. According to the diffraction equation and the angle position of the torsion element, the diffracted monochromatic radiation parts from the wavelength dependent direction and leaves the diffraction grating as a parallel bundles towards the collimator mirror **11**. The collimator mirror then reflects and focuses this partial radiation in different wavelength dependent focal points. Now the exit slit aperture **19** selects partial radiation of a narrowed wavelength range and redirects it towards the exit optical waveguide **14**.

[26] An additional design of the invention is defined by the replacement of the described slit apertures using sufficiently large slits in the monolithic base body of the torsion element, whereas the aperture slit is replaced with the front of an optical waveguide or by a suitable small radiation detector in the focus of the collimator optics.

[27] **Figure 4** is a schematic side view of the design according to **Fig.3**. In this case the slit apertures **18, 19** are arranged on the rotation axis of the torsion grating **6** as previously utilized in

Fig. 3. The space between both back electrodes **7, 8** can be used to guide the polychromatic radiation to the slit apertures or to extract the monochromatic radiation, respectively. Furthermore, the spatial location of the slit apertures always remains consistent and the slits remain exactly in the focus point of the collimator mirror **11**. In the preferred example, entrance and exit slit apertures **18, 19** are designed within the area of the diffraction grating **5a**. One result of the inventive slit design is that the parallel radiation reflected from the collimator mirror propagates very close to the axis in relation to the optical axes **20, 21**, which are defined by the focus according to the entrance slit apertures **18, 19**.

[28] Another advantageous development of the invention consists of monolithic body **17**, torsion spring **15**, torsion element of the torsion diffraction grating **6**, planar reflector and electrodes of the electrostatic drive **7, 8** with a fixed external diffraction grating **5** instead of the torsion diffraction grating, while the entrance and exit slit apertures are arranged on the monolithic body **17** of the torsion mirror.

[29] **Figure 5** is an extension of **Fig.3 and 4** where optical waveguides **13, 14** are discussed, which are fed directly through to the backside of the slit apertures **18, 19**. In further designs of the invention the slit aperture can be directly confronted with the radiation to be analyzed by means of a prefixed optic or a Light Emitting Diode (LED) directly fixed at the electrode mounting as a monitor radiation source. Via design of further slit apertures **18, 19, 22, 23, 24, 25, 26, 27, 28** within the monolithic body **17** of the torsion diffraction grating – many more configurations can be achieved as schematically shown in **Fig 5**. The present invention also relates to several independent simultaneous monochromator channels, which can be created as diverse designs.

[30] One application example of the monochromator for transmission measurements includes slit apertures **18, 19** of the sample-sided first monochromator channel, slit apertures **22, 23** of another sample-sided monochromator channel, furthermore slit apertures **27, 28** of a reference channel for radiation source compensation, as well as slit apertures **24, 25** (in front of LED and detector) of a monitor channel for phase control of the angle movement of the torsion grating.

[31] **Figure 6** shows the applications of our microspectrometer micro scanning mirror **38**. The mirror is manufactured using micro system technology and operates in a resonance mode. In addition the mirror is driven by a controlled alternating high voltage signal (approximately 500 Volts). The polychromatic radiation from a broadband IR light source **30** is focused onto the spectrometer entrance slit **32**. Then a paraboloidal reflector **36** is used to produce a parallel beam to illuminate the micro mirror **38** and diffraction grating **40**. The radiation of the first order of diffraction from the grating **40** is then focused via the paraboloidal reflector **36** onto the detector slit **42**. The analyzed wavelengths are essentially determined by the incidence angle of the radiation onto the grating **40** according to the temporary mirror angle. Consequently, the spectrum is continually scanned over the detector slit **42**, as a function of the mirror rotation angle. The NIR (Near Infrared) and MIR (Middle Infrared) radiation, modified by the sample interaction, is detected and amplified by the IR detector system **44**. Due to the control of the mirror angle the observed signal can be assigned to the respective wavelength. From the measured spectra, characteristic molecular band positions and intensities can be determined for characterization of the sample **34**.

[32] These types of ultracompact micromirror spectrometers can be applied to many fields, namely: (i) non invasive medical diagnostics (ii) monitoring of biochemical processes (iii)

surface diagnostics of numerous materials (iv) diagnostics of human tissues (v) characterization of the quality of food (vi) pharmacological products and cosmetics (vii) characterization and treatment of aging of skin (viii) detection of toxic gases and fluids (ix) biological warfare agents and bacterial spores in the MIR range. This approach utilizes extinction and scattering measurements to characterize the spectral fingerprints of bacterial particles.

[33] CONCLUSION

[34] Although the description above contains many specifications, these should not be construed as limiting the scope of the invention but as merely providing illustrations of certain embodiments of this invention. Thus, the scope of the invention should be determined by the appended claims and their legal equivalents rather than by the examples given.